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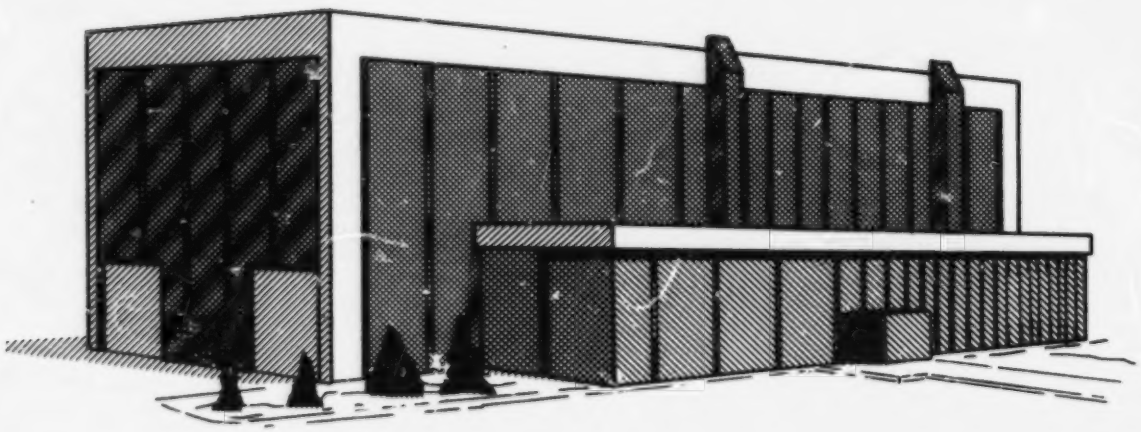
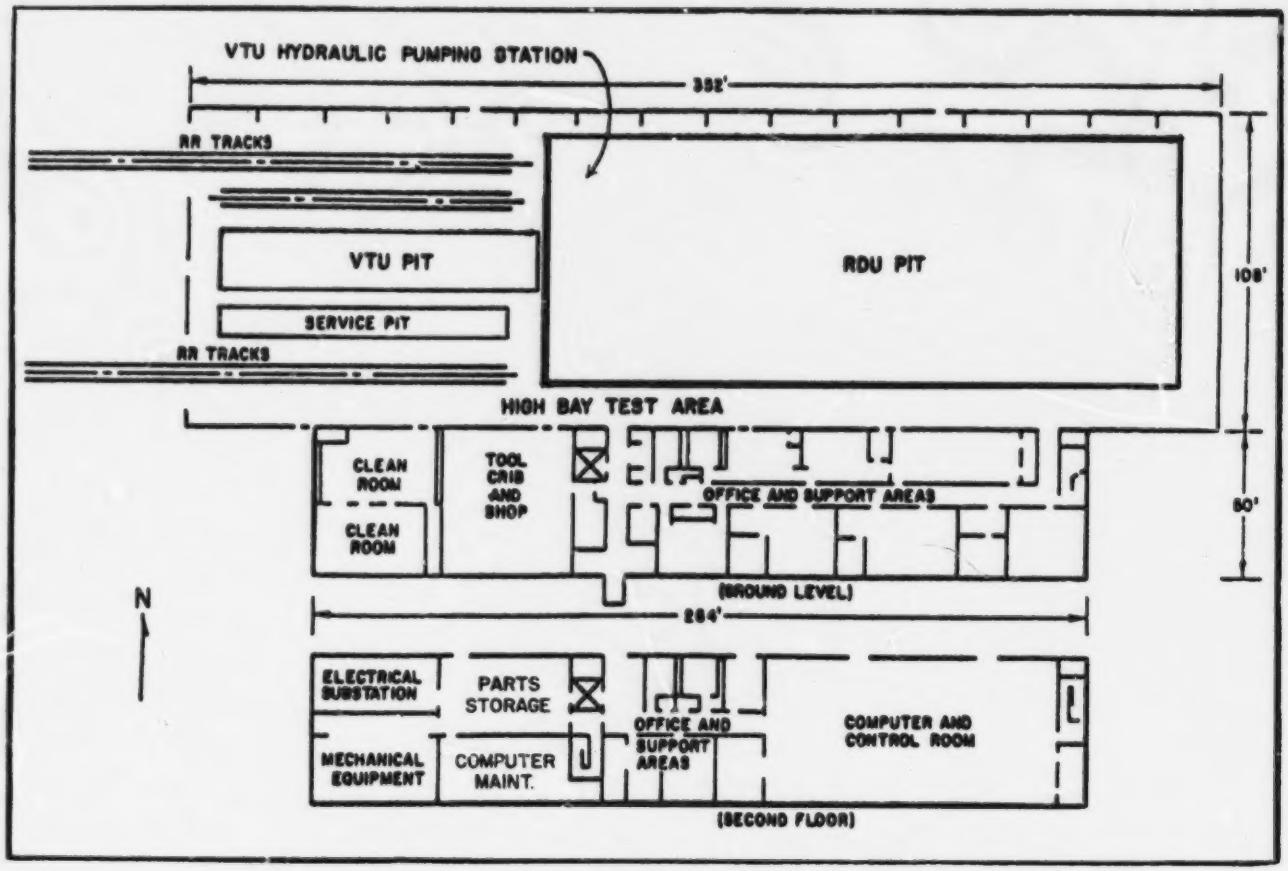
THE RAIL DYNAMICS LABORATORY:

CAPABILITIES/TESTS

COMPLETED
30

ORIGINAL





RDL Building Floor Plan

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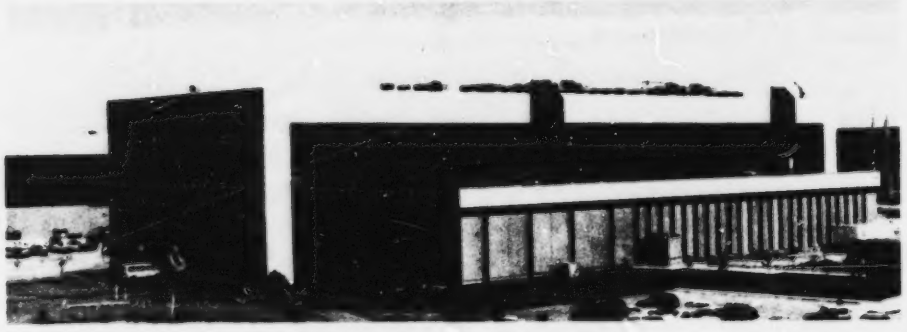
Introduction to the Rail Dynamics Laboratory

Improved equipment safety and performance is a fundamental requirement for the future vitality of the national rail system and is one of the major goals of rail research and development sponsored by the Federal Railroad Administration (FRA) of the United States Department of Transportation. The wide variety of locomotives and cars used to transport freight and passengers by the nation's railroads possess inherent performance limitations which must be overcome to provide cost-effective transportation. Vehicle, structural, and rail/wheel interface dynamics present the most complex and formidable challenges to improved safety and performance and require commensurate testing programs to develop successful solutions.

The Rail Dynamics Laboratory has been built to provide a powerful test tool for investigating the complete range of rail dynamics phenomenon.

The Laboratory capability is embodied in the Roll Dynamics Unit (RDU), a test machine for imparting rotational excitation to the wheels of a rail vehicle, and the Vibration Test Unit (VTU), a test machine for imparting vertical and lateral excitation to the wheels of a rail vehicle. Test conditions are monitored and controlled by the RDU and VTU control systems and a pair of minicomputers. Test vehicle responses to the excitation are sensed, processed, and recorded by a data acquisition system which also uses one of the minicomputers.

Since the RDL construction was completed in 1980, five test programs have been conducted using the VTU and RDU. The intent of this document is to describe the RDL capabilities and the scope of these tests. Sample data displays are included to provide the reader insight into benefits which can be realized from an RDL test.



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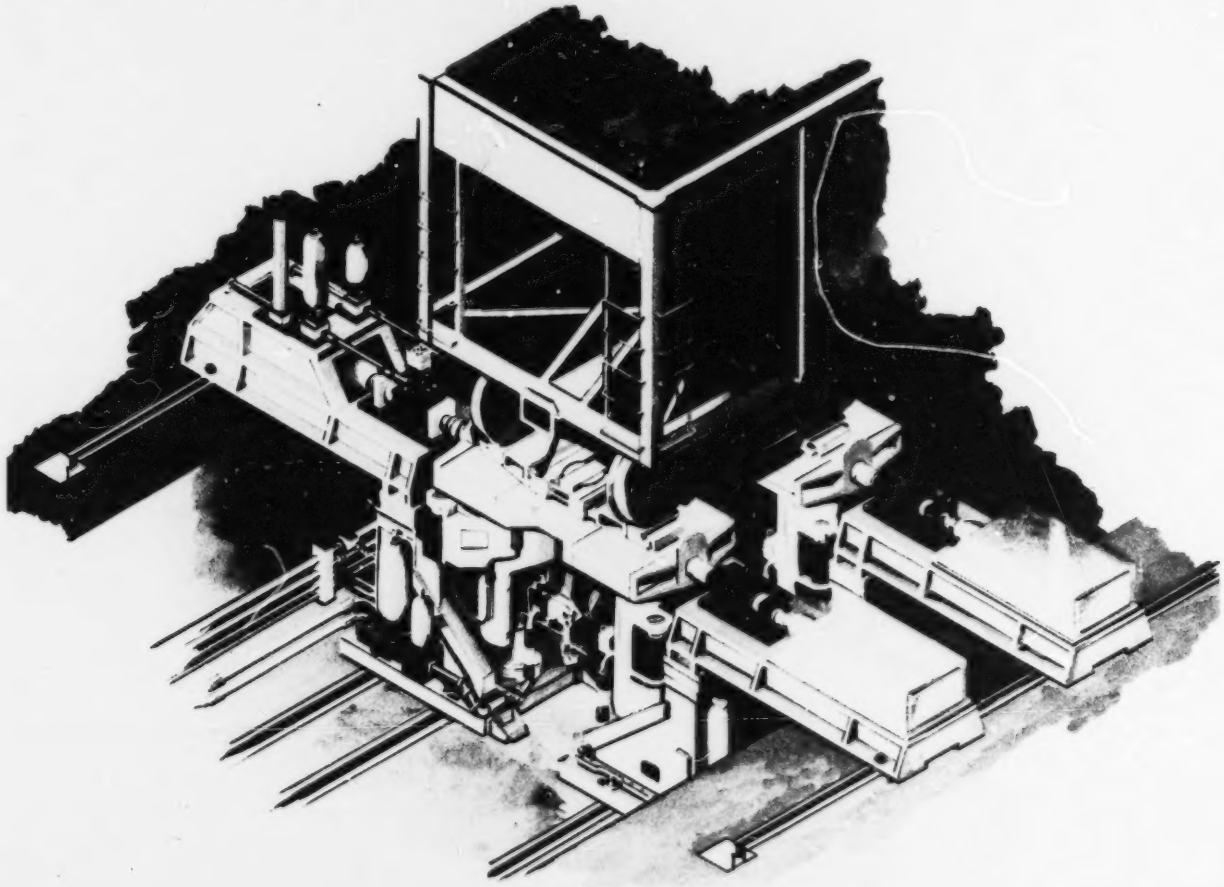
The Vibration Test Unit

The VTU subjects a stationary rail vehicle to controlled vertical and lateral vibration inputs at the wheels, thus creating the dynamic effects of perturbed track on a moving vehicle. The VTU is equipped with 12 hydraulic shakers to apply these inputs; 8 of the shakers vibrate vertically and are positioned under each wheel of the test car; 4 of the shakers vibrate horizontally and are in line with the axles to move each pair of wheels laterally. Elaborate bearing assemblies are provided to mate the car wheels with the shakers and to allow simultaneous vertical and lateral motions.

Displacements with a stroke range of 4 inches vertically and 3 inches laterally can be applied. The displacement time histories of these shakers are produced by the VTU control system from computer-generated waveforms. The VTU operates over a nominal frequency range of 0.2 to 30 Hertz and can produce a wide variety of motions. Sinusoidal, impulse, or random forcing functions in pure or combined vertical, lateral, roll, yaw, pitch, or an arbitrary direction can be applied to meet test requirements and subject a test vehicle to almost any condition. Test inputs are repeatable for comparisons, even after a lapse of time due to the computer controlled input capabilites.



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In order to accommodate the variety of railcars available or planned, the VTU is constructed in a modular configuration. This design provides a flexibility to accommodate cars with quite different lengths, axle spacing, truck spacing, and overhang. In addition, system safety interlocking features have been incorporated to protect both the VTU and test vehicle from damage resulting from high inputs or unstable responses.

Details in addition to those listed below on the VTU capability can be found in the "Rail Dynamics Laboratory" brochure.

Vehicle Length (max)	90.0 ft (27.43 m)
Vehicle Width (max)	12.0 ft (3.66 m)
Vehicle Weight (max)	320,000 lb (145,150 kg)
Axle Load (max)	80,000 lb (36,287 kg)
Truck Center Distance	
(min)	20.0 ft (6.10 m)
(max)	70.0 ft (21.34 m)
Truck Axle Spacing	
(min)	54.0 in (1.37 m)
(max)	110.0 in (2.79 m)
Gauge (min)	56.5 in (1.44 m)
(max)	66.0 in (1.68 m)

With controlled excitation inputs to the test vehicle, such conditions as rock and roll tendencies, suspension behavioral characteristics, resonant frequencies, ride comfort, lading resonant frequency, and lading response and component fatigue can be achieved.

Although its primary use has been directed towards the testing of railroad freight cars, the VTU is a very adaptable mechanism. Future tests can evaluate transit cars, lading damage, truck safety and improvement, locomotive stability characterization, road vehicle testing (including cars, tractor-trailers, buses and heavy equipment), military equipment testing of personnel carriers, strategic equipment and materials carriers, seismic simulation testing, fatigue tests, and accelerated service tests.

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The Roll Dynamics Unit

Through a system of drive motors, flywheels and rollers, the RDU is capable of simulating relative motion for both unpowered vehicles, such as boxcars and passenger cars, and for absorbing power produced by self-propelled vehicles, including locomotives and transit cars. Vehicle speeds in excess of 140 miles per hour can be simulated. The unit is composed of modular elements which can be positioned to match various truck spacings, axle spacings, and rail equipment gauges as depicted in the table.

Vehicle Length (max)	108.0 ft. (32.92 m)
Vehicle Width (max)	12.0 ft. (3.66 m)
Vehicle Weight (max)	400.000 lb. (181.437 kg)
Axle Load (max)	100,000 lb. (45,360 kg)
Truck Center Distance	
(min)	69.0 in. (1.75 m)
(max)	80.0 ft. (24.38 kg)
Truck Axle Spacing	
(min)	69.0 in. (1.75 m)
(max)	110.0 in. (2.79 m)
Gauge (min)	56.5 in. (1.44 m)
(max)	66.0 in. (1.68 m)
Powered Axles	Fou·

Each test vehicle wheel rests on and is driven by a supporting roller. Each pair of rollers mounted on a common shaft, is attached to a drive train which provides inertia. This interface between the vehicle wheelset and the roller pair simulates the vehicle traveling over track. The roller rotation simulates vehicle velocities on tangent track having no lateral or vertical irregularities, and also simulates flat curve geometry. Through its flywheels, the RDU is able to simulate resistive forces associated with accelerating or braking of a vehicle.

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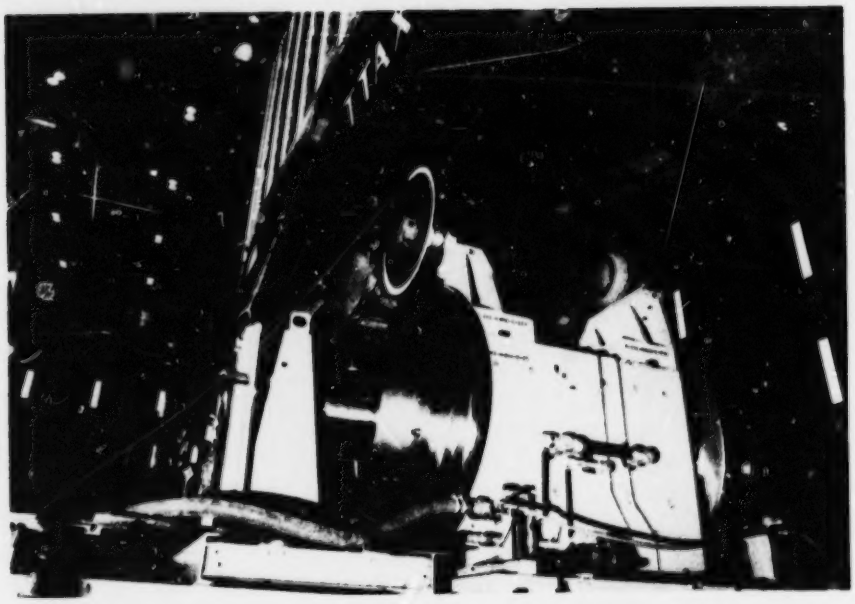
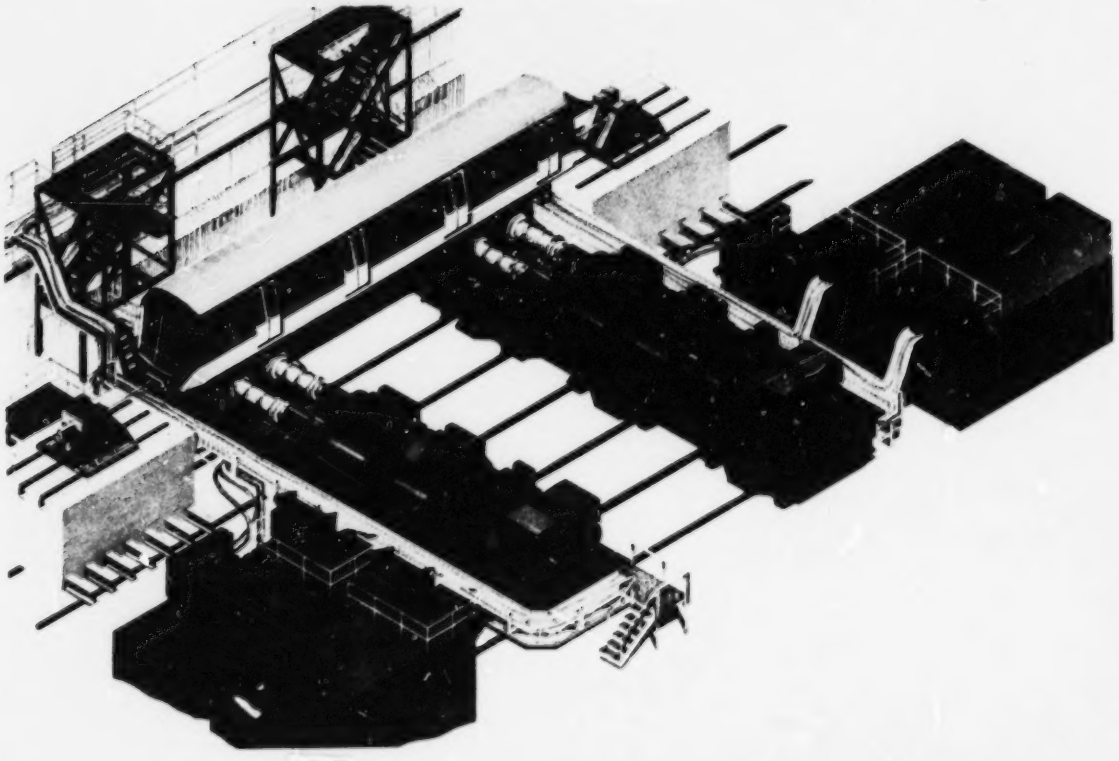


The RDU will support and drive the wheelsets of a four-axle rail vehicle or locomotive truck. Six- or eight- axle locomotives and cars can be tested with the use of auxiliary support stands. The laboratory is equipped to duct off the exhaust produced during locomotive tests and can supply direct current electrical power for testing transit vehicles.



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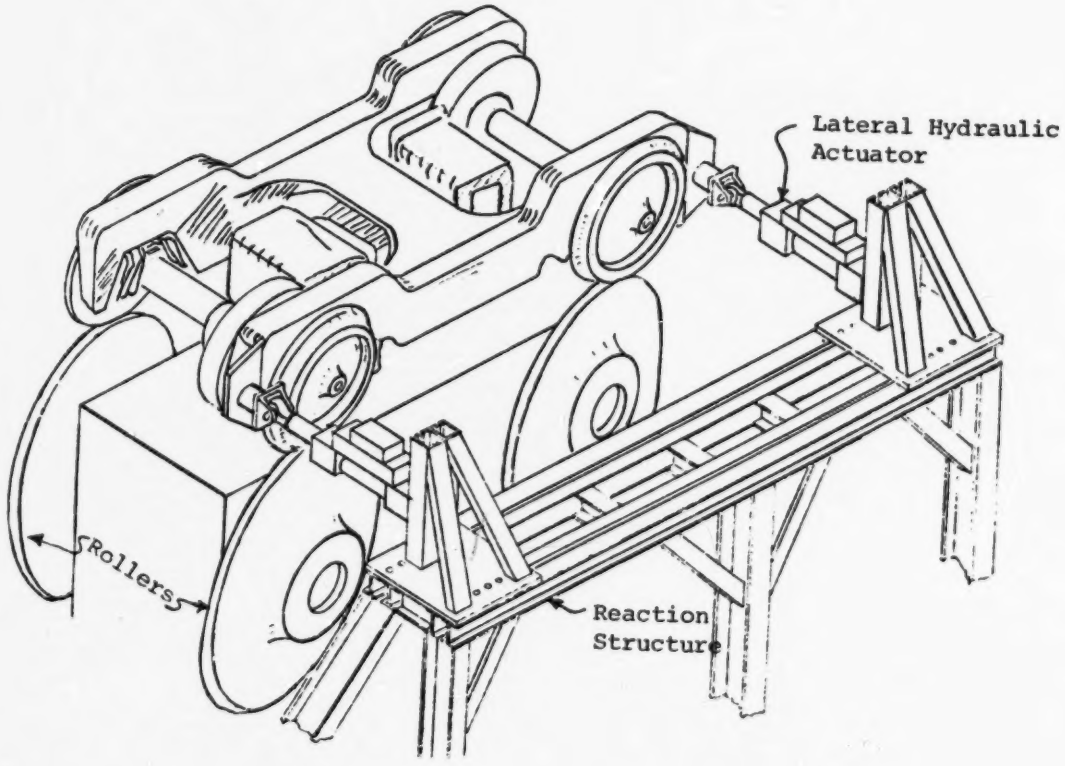
The RDU is equipped with a reaction frame which provides a mounting base for two hydraulic actuators. These actuators can be positioned, as shown in the illustration below, to apply lateral forces to the side frame of a truck. The forces can be either steady or vibratory, and the pair of forces can be either push-push (against the truck side frame) or push-pull.

This setup provides a very precise, versatile test tool when complemented with high resolution displacement instrumentation. The lateral position or motions of both wheel sets can be measured very precisely for a wide range of wheel rotational speed and lateral force combinations. Meticulous evaluation of these measurements provides insight into the fundamental engineering quantities affecting the lateral stability of a truck (i.e., the hunting tendency of the vehicle).

This arrangement depicts some of the versatile and unusual test capability which can be obtained from application of RDL equipment.



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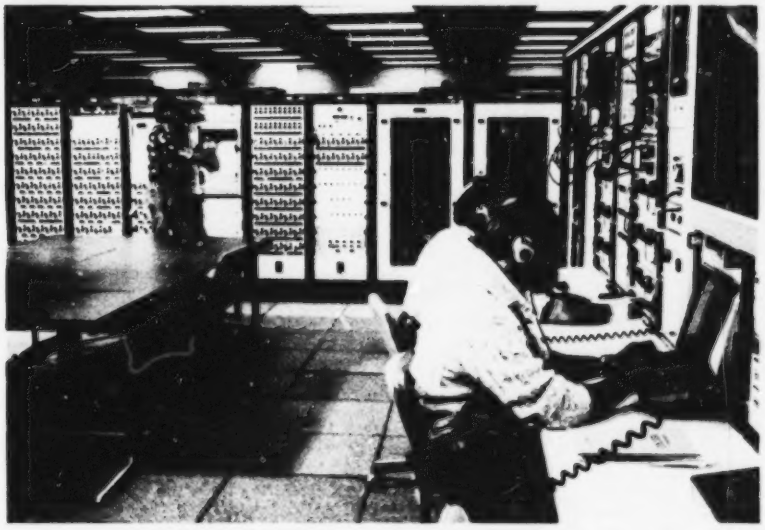
Support Services and Functions

RDL testing entails a number of other functions to support operations on the VTU or RDU. Data acquisition consists of up to 128 channels of different types of signal conditioning, with digital recording of all channels and analog magnetic tape and oscillograph recording of selected channels. The digital recording capability includes an additional 128 channels which are assigned to measurements of VTU or RDU system values. A closed circuit television system enables simultaneous and selected viewing of four camera images as well as split screen viewing of two images, or recording of one selected image. Offices and observation rooms are available for customers, analysts, and representatives.



VTU CONTROL AREA

In addition to RDL test facilities, substantial support resources are available at the Test Center. A complete machine shop is maintained for repair or construction of test devices. Also on site are locomotive and railcar repair facilities, and electrical, welding, woodworking, paint, sheet metal, refrigeration, and automotive shops. A complete metrology laboratory is available to maintain and calibrate test instruments.

The Component Test Laboratory is equipped with a truck loading device which enables railcar trucks to be characterized for discrete evaluation as a subsystem, or for correlation with mathematical models of a complete vehicle.

These test and support facilities are manned by experienced personnel including design and analysis engineers, test conduct engineers, data technicians, instrumentation engineers and technicians, computer programmers and operators, and craftsmen of all kinds.

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Data Processing and Display

Test data acquired during a test run is converted from its raw digital form to processed engineering values by data processing computers. The primary capability is embodied in a PDP 11/60 with peripheral graphics terminals, hard copiers, pen plotter, line printer, magnetic tape drives, and magnetic disc drives. Data reduction is accomplished on the 11/60, and data files created and stored on a mass storage device. Original test data can be stored on magnetic tapes in digital form, as well as on analog tapes, and preserved in the Test Center archives for prescribed periods. Analog data reduction capabilities and digitization of real time analog test data can also be provided.

PDP 11/60
COMPUTER SYSTEM

Data processing products include a wide variety of tabular and graphic formats. Software programs provide both time domain and frequency domain analyses. Curve-fitting and filtering routines are available to edit and format the data. Plotting formats include power spectral density, cross-spectra, transfer functions, transmissibility, random decrement, peak detection, rain flow counting, calculation of stress and strain, 1/3 octave spectral analysis, two-degree of freedom modal analysis, and differentiation and integration of files.

Two mathematical models are programmed on the TTC general purpose computer, a Honeywell 66 DPS, for use in simulating revenue service under laboratory test conditions. One is an asymmetric wheel/rail contact characterization program. This program uses iterative procedures to determine nonlinear functions like effective conicity, gravitational stiffness, and other engineering values pertinent to evaluating wheel/rail contact conditions and the effect of these conditions on railcar dynamic stability. The second model is a curving model which uses some of the output from the previous program and quantifies the curving stability of rail vehicles.

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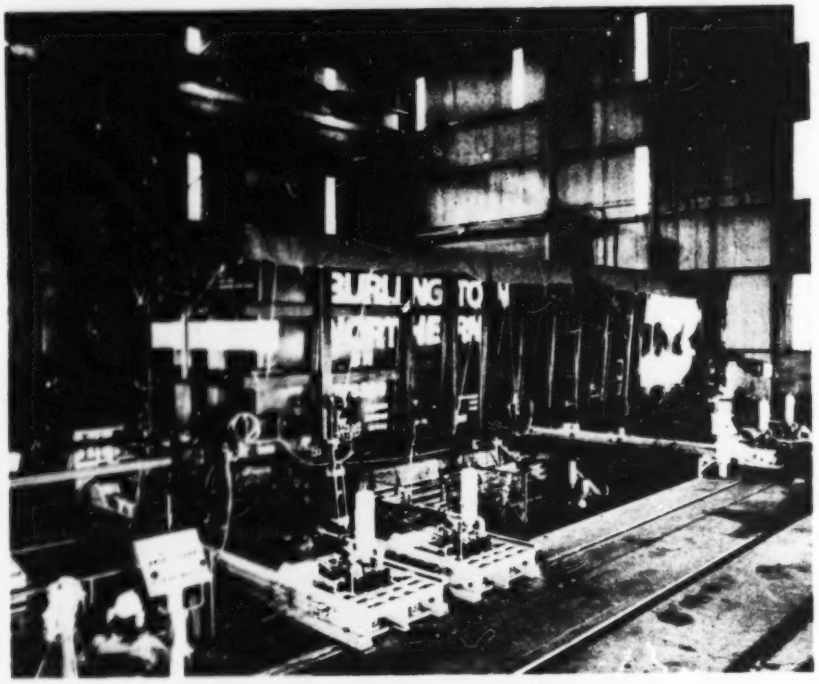
Since the start of operations in 1980, the RDL has conducted five test programs. Results of these tests will form the nucleus for continued research to identify improvements for today's railroad and transit systems. Brief descriptions of test objectives, conditions, configurations, and results follow.

Gondola Demonstration Test

The first VTU test program demonstrated an approach to structural freight car dynamic testing not available anywhere else in the United States. Using electronically controlled, hydraulically actuated test equipment with reapeatable test input, data was collected and reduced for design purposes and for comparison with existing mathematical models. Selected suspension components were also evaluated in accordance with the manufacturers' specifications.

It also demonstrated the VTU capabilities for evaluation of vehicle and structural dynamics. The test vehicle, a high sided gondola car, donated for testing by the Burlington Northern Railroad, was subjected to vibrational excitations using various suspension and lading configurations.



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Four vehicle configurations were tested. Three configurations of the loaded car weighed 260,900 pounds (100 tons of coal), and the fourth configuration included only the empty car which weighed 60,900 pounds. Two different types of trucks and selected suspension components were used in the three loaded and one unloaded configurations. One loaded (1#) and the unloaded configuration (4#) used the same truck and suspension components to obtain comparable results. The specific suspension components were chosen for comparison of test data from these tests with mathematical model simulation and perturbed track test data.

The electro-hydraulic actuator-excited inputs to the high-sided gondola were governed by the following VTU modes of operation:

ACTUATOR MODE		CONTROL SIGNAL
Lateral		Sweep at maximum amplitude
Torsion		Sweep at constant acceleration
Bounce		Torsion Decay
Roll	<-->	Sweep at constant velocity
Pitch		Random
Yaw		Full Wave Rectified
Independent		Sinusoidal
		Track Geometry

There were 124 instrumentation channels, including pressure, strain, accelerometer and roll-rate gyro, and 107 system control channels digitally recorded during this program. Selected analog channels were recorded along with oscillograph recordings. For certain configurations, spectral displays were also plotted during the runs. The essential trend of these results is presented here.

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CARBODY AND SUSPENSION RESPONSES

Data were obtained for all conditions, but for brevity, only bounce and roll modes will be presented. Frequencies at which individual outputs had large responses followed by decay were noted and identified as resonant frequencies. A group of at least five channels was evaluated for a large response to the excitation mode before positively identifying a resonance.

The carbody resonant frequencies for configurations #1 and #4, bounce and roll excitation modes are presented in the table below.

BOUNCE AND ROLL EXCITATION MODES.

Excitation Mode	Resonant Frequencies (Hz)	
	Conf #1	Conf #4
	Ladened Car	Empty Car
Bounce	2.4	2.9
Roll	0.7	1.1

DAMPING and TRANSMISSIBILITY

Evaluation of railcar vibration requires knowledge of the vibratory energy flow through the car trucks and structure. To remedy any undesirable condition, the analyst needs to know the vibration amplitudes, responsive (or resonant) frequencies, damping, and other parameters. Railcar vibration tests are designed to provide these parameters in both tabular and graphical form and to show how vibration in one part of a car relates to vibration in another part through structural transmissibility. In this context, the ratio of the amplitude of the transmitted motion to the impressed or exciting motion is called transmissibility.

Friction snubber damping in the trucks is a highly nonlinear, nonrepeatable phenomenon which can be best evaluated with statistical techniques. Accordingly, measures of damping are extracted from the test data through several data processing techniques.

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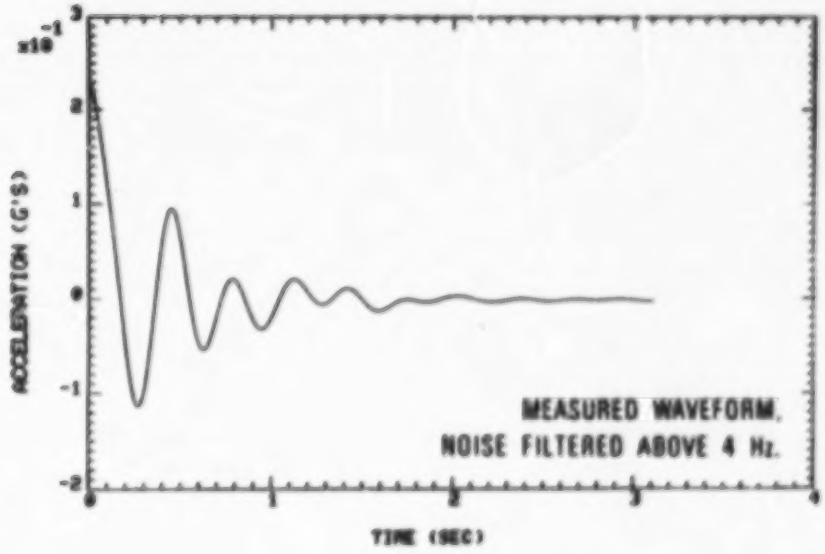
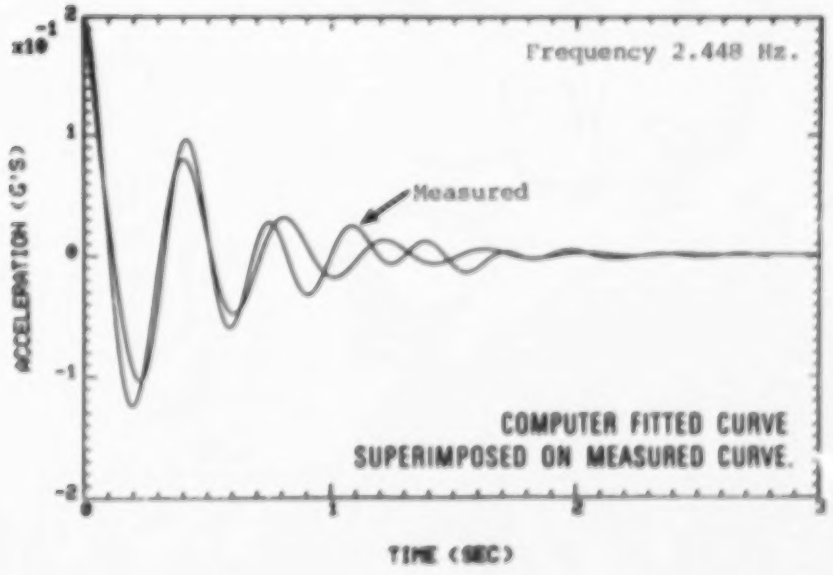
One techniquc is to fit a decaying vibration wave form with an exponential decay sinusoidal curve (in the time domiin) and compute the applicable damping value. An example of such a curve fit is shown below with a damping ratio of 15%. Note that the scale factors for these two plots differ.





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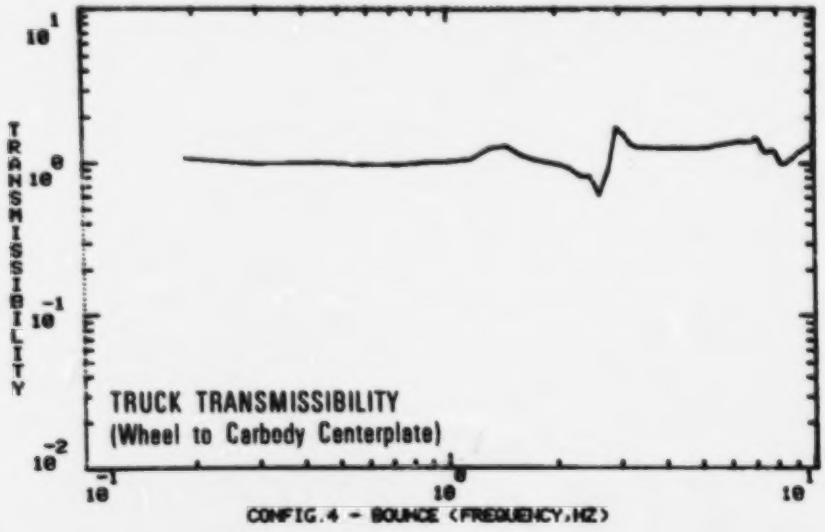
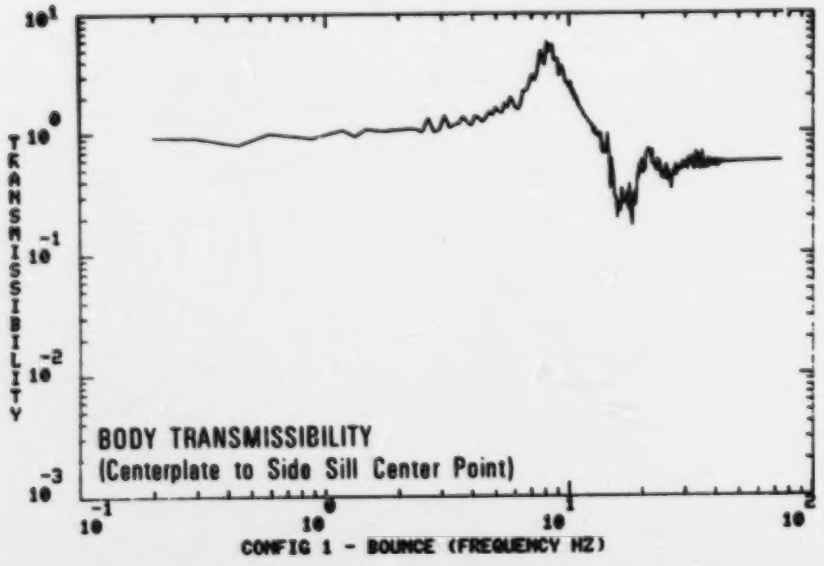
Transmissibility plots represent the gain ratio between two points on the vehicle such as midpoint of a side sill and carbody bolster. For the gondola car testing, two transmissibilities were computed. One presented the transmissibility from the vehicle wheel to the body centerplate, and the other presented the transmissibility from the centerplate to carbody side sill at the center. These data were obtained from runs with a sinusoidal excitation of the wheels over a spectral range of 0.2 to 24 Hz. The total package of transmissibilities were produced for configurations #1 and #4 for the bounce, roll and lateral modes of VTU operation. An example plot is shown here with the data displayed on a log-log scale format. The maximum peaks indicated by transmissibilty plots show conditions of resonance.



Note that the scale factors for these two plots differ.



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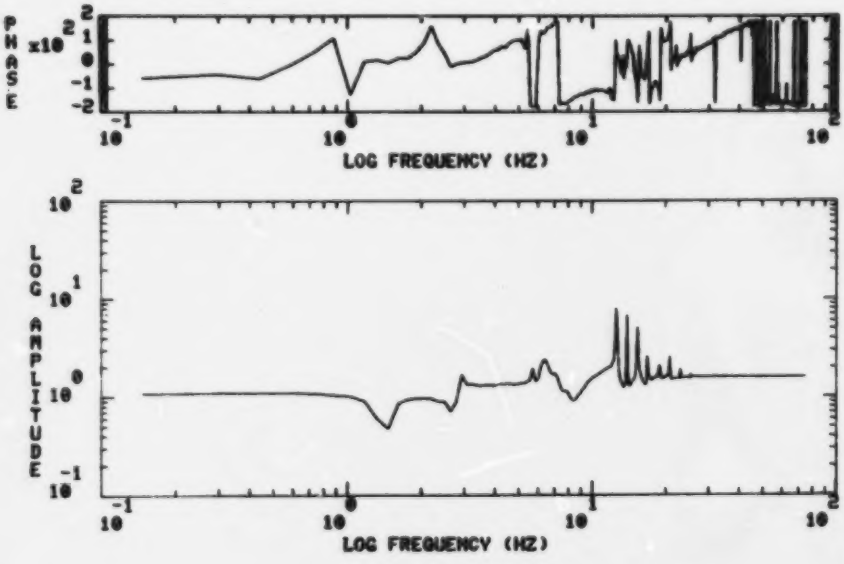
MODAL ANALYSIS

Modal analysis is a technique which makes use of transfer functions to identify conditions of resonance in carbody vibration. Transfer function plots (also called "Bode" plots) show the amplitude ratio and phase difference between response and input measurements.

Whenever an abrupt change of phase and a peak amplitude occur simultaneously a resonant condition may exist. The modal analysis procedure uses Argand plots to determine the modal amplitude of a resonance. In this procedure, data from the Bode plots are plotted on the real (horizontal) axis and imaginary axis (vertical) to produce an Argand plot. The software then fits a circle by the least squares method to the data points between frequency limits set by the analyst. The software also identifies the resonant frequency and calculates the sinusoidal amplitude which is the diameter of the circle. Mode shape plots and tabulations of mode shape coefficients are computed from the Argand plots. These data can be used to examine maximum energy transfer in a carbody at individual frequencies and allow "graphically represented mode shapes" to be used as a visual aid in identifying the adverse effects of car resonances.



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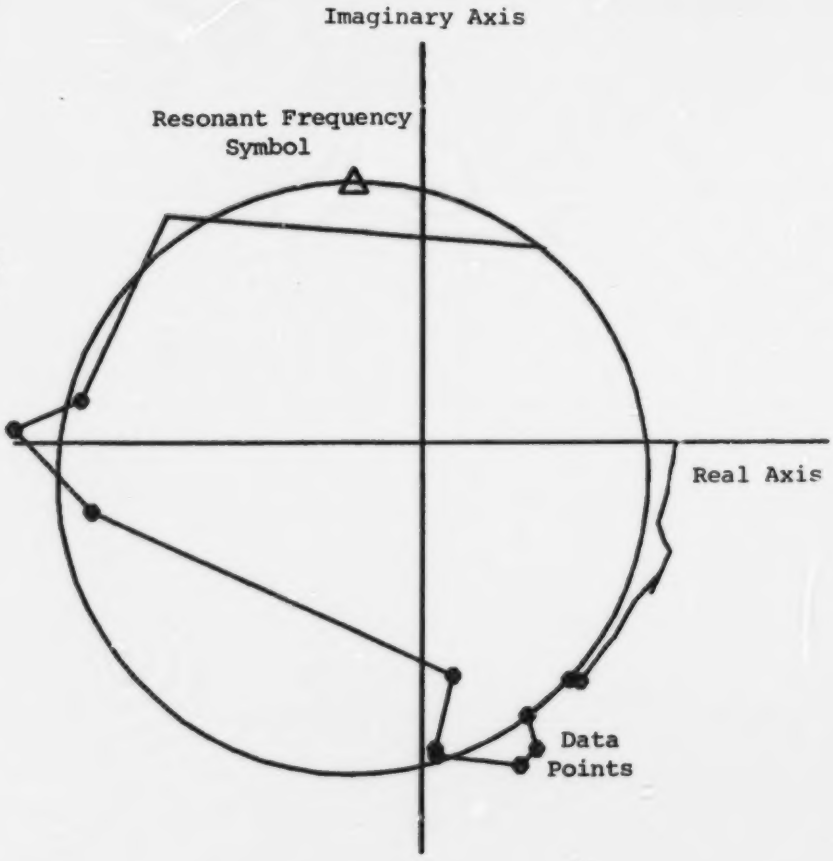
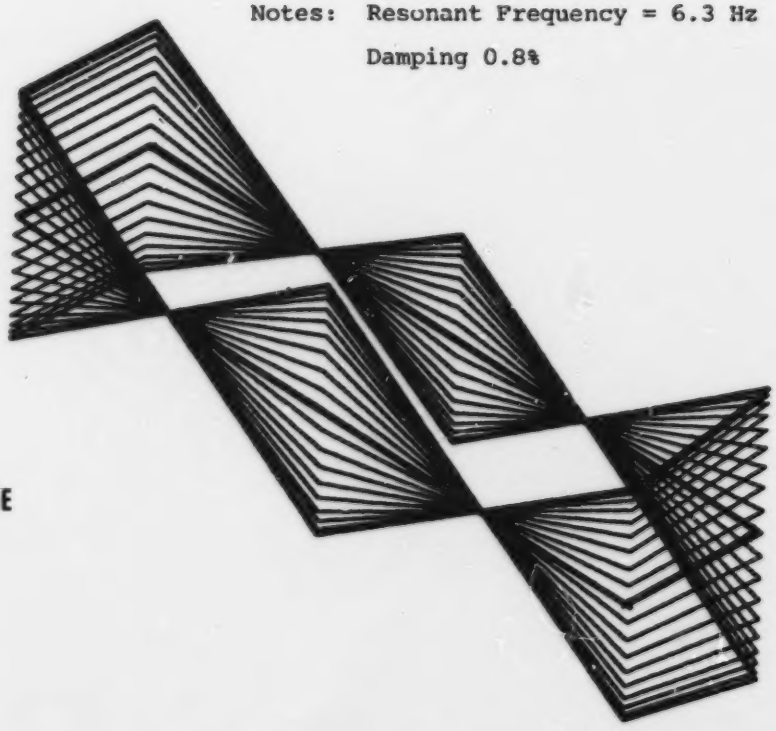
ARGAND PLOT WITH CIRCLE CURVE FIT SUPERIMPOSED OVER DATA POINTS



Notes: Resonant Frequency = 6.3 Hz

Damping 0.8%

FIRST FLEXIBLE BODY BENDING MODE



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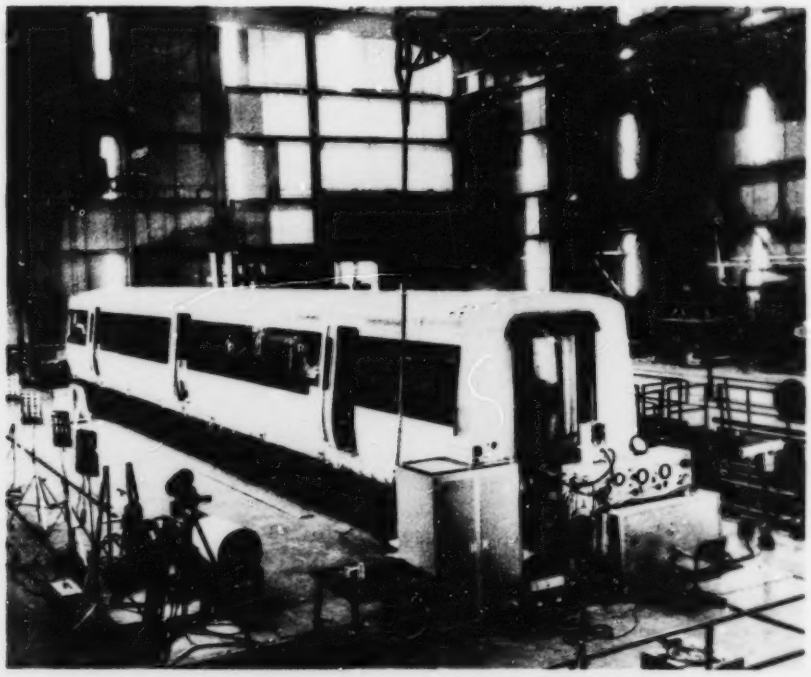
MARTA Car Dynamic Shake Test

A requirement arose to verify the vibration modes of the Metropolitan Atlanta Rapid Transit Authority (MARTA) car. This test used a single hydraulic shaker to vibrate the carbody through an attachment at one end. A variety of runs were performed which excited vertical, lateral, and torsional motions in the carbody. Data were recorded for both rigid and flexible modal responses and for resonances of major under-floor equipment installations.

Post-test analysis of the data was used to validate mathematically derived modal frequencies and shapes, interpretation of ride quality data from track tests of the car, and documentation of floor-mounted equipment resonant frequencies and damping.



For each mode excited during the vertical shake tests, the relative motion amplitudes and phases were extracted for selected measurements. This information was used to plot mode shapes manually which illustrate the significant bending modes. The same data reduction procedure was used to obtain the lateral and torsional mode shapes shown here.

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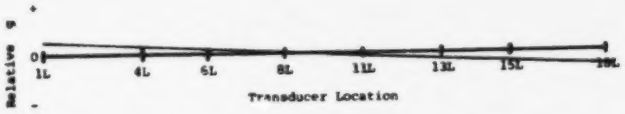
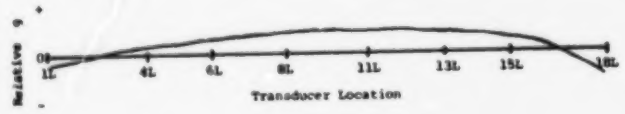
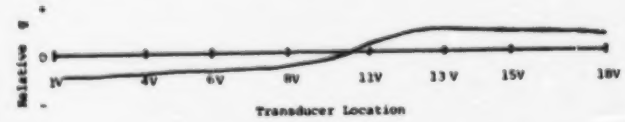


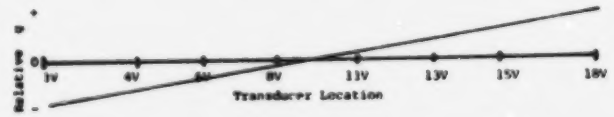
Rigid Body Yaw 3.5 Hz



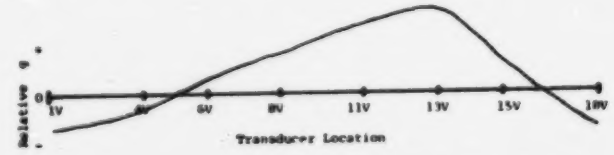
First Lateral Bending 8.75 Hz



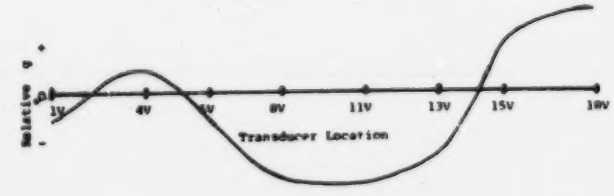
Torsional Bending 12.5 Hz



Rigid Body Pitch 1.5 Hz



First Vertical Bending 7.0 Hz



Second Vertical Bending 8.5 Hz

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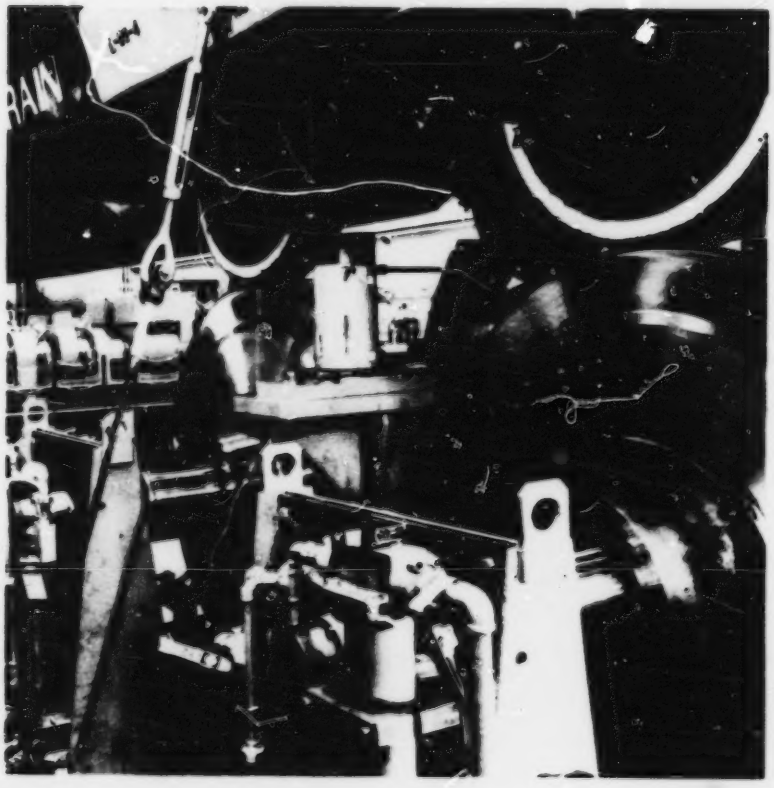
Flatcar Demonstration Test

The primary objective of this test was to obtain data which could be used to evaluate lateral stability characteristics (hunting) of a railroad freight vehicle which is known to have a low stability margin. The test data includes a broad range of parameters applicable to determining hunting characteristics. The results are being used to validate a lateral stability mathematical model developed by the Association of American Railroads.

The flatcar was tested in three configurations on the RDU, with subsequent testing of one of these configurations on the TTC Railroad Test Track (RTT). The four different test configurations were:

- Configuration I - Roller side bearings with service worn wheels, tested on RDU.
- Configuration II - Constant contact side bearings with service worn wheels on the RDU.
- Configuration III - Roller side bearings with new AAR/1:20 tread profiled wheels on RDU.
- Configuration IV - Roller side bearings with service worn wheels on the RTT.



FLATCAR TRUCK
RESTING ON 60" ROLLERS

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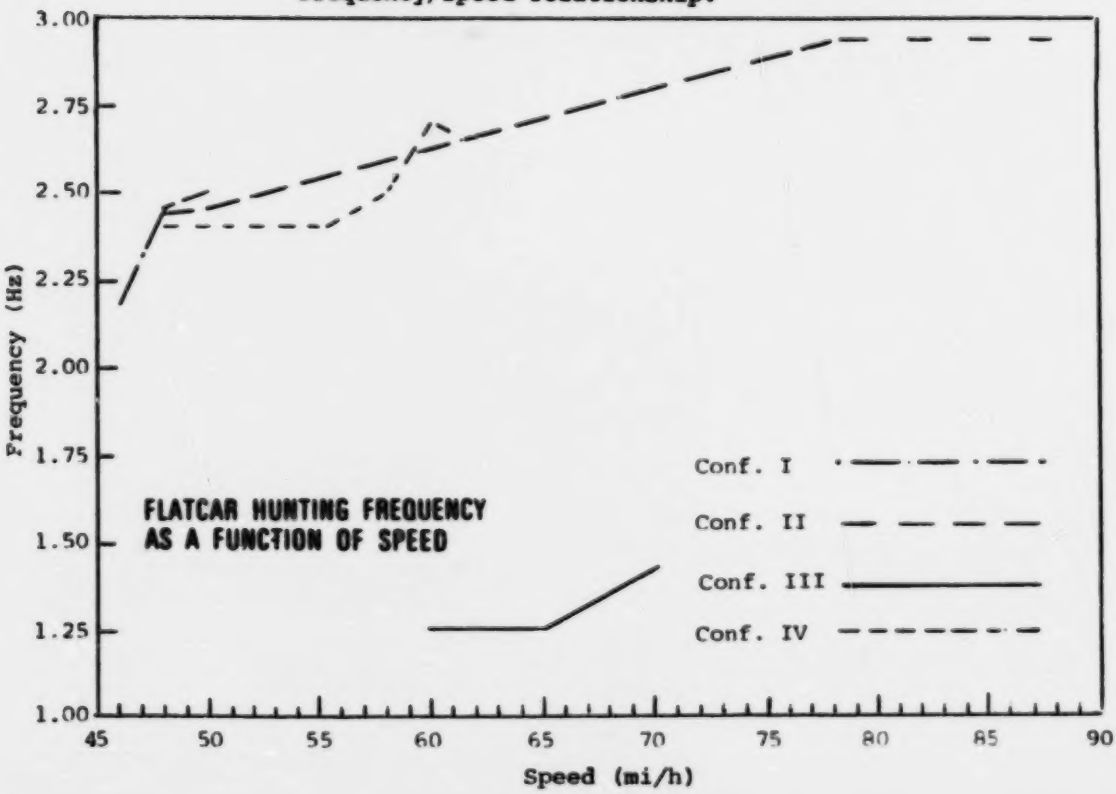
The test sequence was arranged to give three separate data sets for lateral stability characterization of the flatcar on the RDU. The track test data were obtained to compare with the RDU data for the same vehicle configuration.

The first data set was collected from runs simulating an increasing car speed from 25 mi/h (vehicle stable) up to a critical speed.

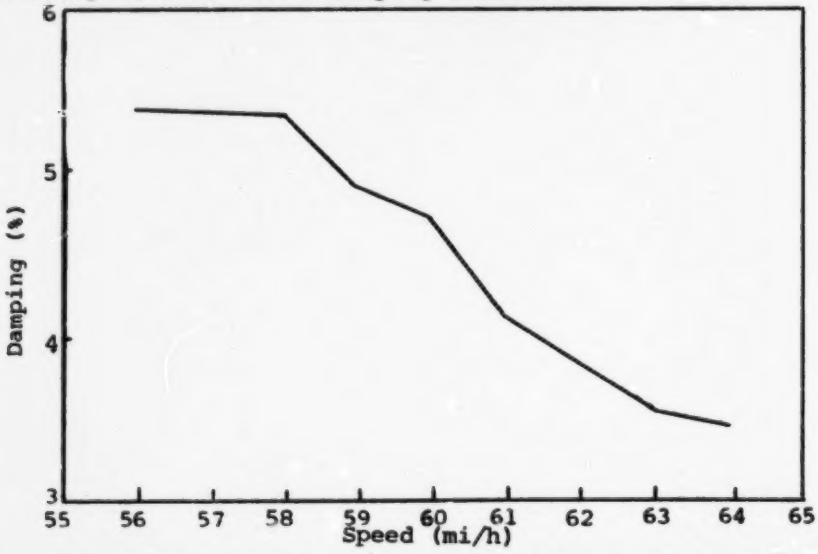
Critical speed was defined as the onset of wheelset lateral oscillations, or "hunting". The second set of runs was to study the damping associated with various truck suspension parameters and wheel profiles. The third data set was obtained by increasing the vehicle speed up to flange hunting of the wheelset and then gradually decreased the speed until hunting ceased.

For the track test, runs were limited to critical speed determination and the full-flanged hunting speed decay.

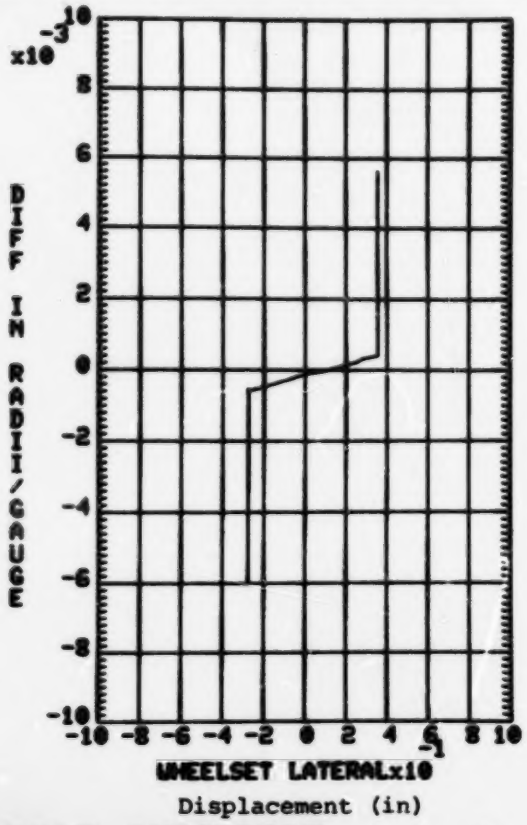
The test results were grouped into three data catagories. The first catagory consisted of hunting frequencies, peak to peak lateral displacements, peak to peak yaw angles, and peak and RMS accelerations--each plotted versus speed. The speed range was chosen to represent values between onset of hunting and full-flanged hunting. The plot below illustrates the dramatic effect of wheel profile on the hunting frequency/speed relationship.



The second category of results consisted of damping values versus speed. The damping values are a percent of critical damping, and were extracted by using a computer technique which curvefits the measured time history data to obtain damping estimates.



The third category of results consisted of effective conicity values obtained from wheel/roller or wheel/rail profile measurements. The effective conicity is computed in terms of rolling radii difference versus wheelset lateral displacement as shown in the sample plot.



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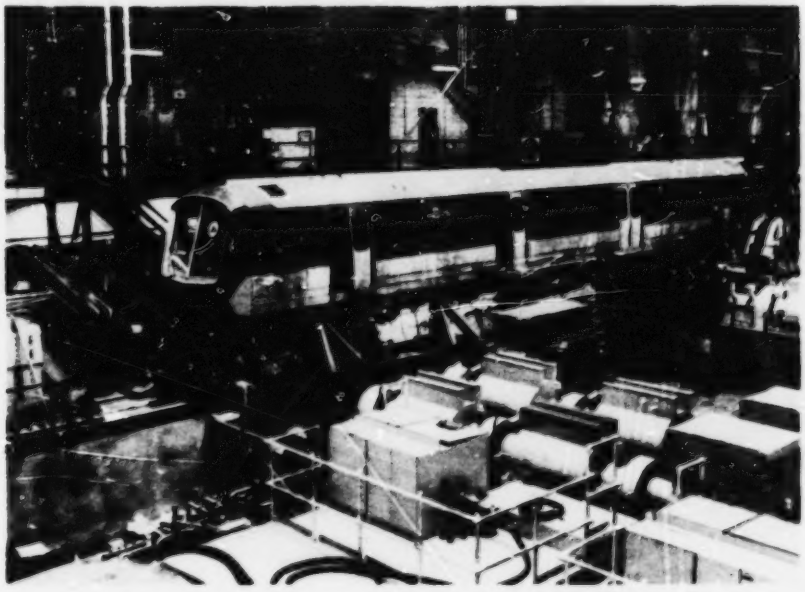
Transit Demonstration Test

A transit car test using the State-of-the-Art Car (SOAC) demonstrated RDU capabilities to evaluate propulsion systems, braking parameters, and energy consumption characteristics. The test also obtained basic performance and dynamic stability measurements that could not be easily or accurately obtained in the track environment.



The SOAC propulsion and ancillary systems were supplied 600 VDC power by the RDL's variable output power supply during the performance tests. The SOAC, under power, provided rotational forces from the truck to the rollers, which simulated aerodynamic drag and rail resistance with reactive torque to produce actual operating characteristics. The simulated conditions produced will allow comparison of previous track collected data to the laboratory performace data.

PERFORMANCE AND POWER TOOLS

The performance tests were subdivided into individual tests as follows:

- Acceleration
- Deceleration
- Traction Resistance
- Spin/Slide
- Adhesion
- Energy Consumption

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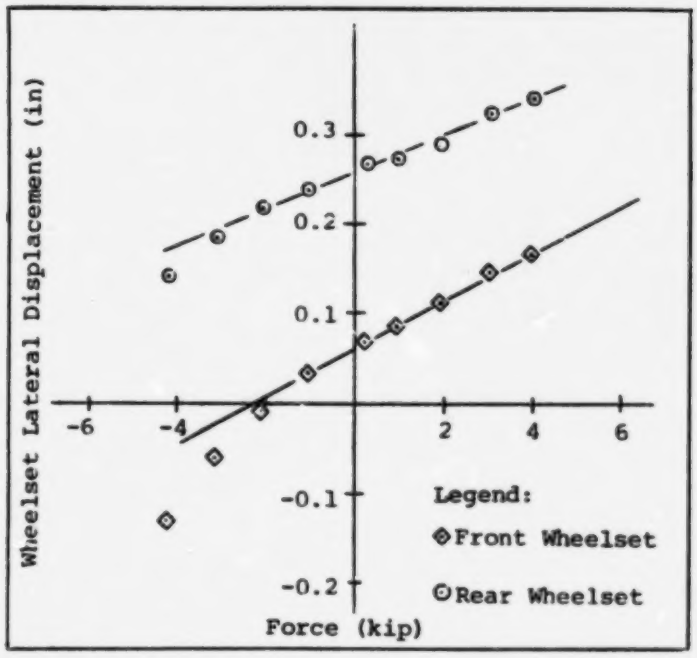
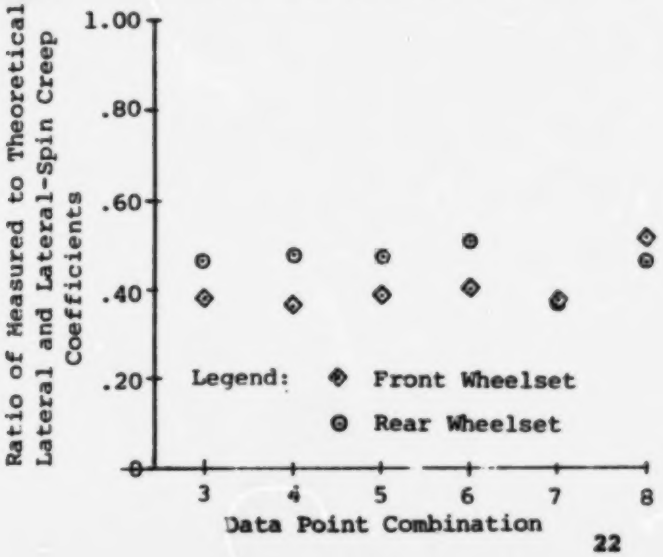
Dynamic stability tests were conducted with the car wheels being driven by the RDU rollers. Two lateral actuators attached to the leading truck sideframe provided the sinusoidal input forces (see sketch on page 6). The lateral actuators also applied perturbations while the roller/wheel combinations were rotating to obtain initial condition response and various damping values. In the creep tests, yaw angles and wheelset displacements were obtained with static forces applied in and out of phase by the lateral actuators. A result of the creep test procedure is shown here.



By using these results in an analysis of wheelset dynamics, it is possible to calculate creep coefficients The output from such a calculation for various combinations of data points is shown below.



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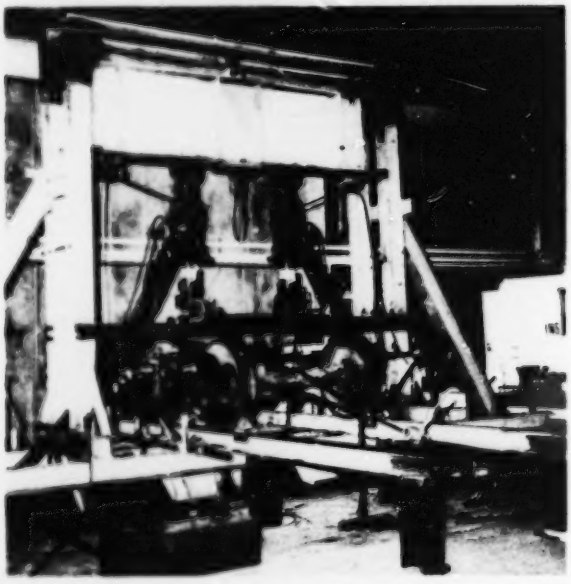
70-Ton Boxcar Validation and Lading Resonance Test

General interest in the coupling of boxcar vibration to the lading carried by the car stimulated this test. A general purpose mathematical model (FRATE) had been developed by FRA several years ago and validated with a flatcar test. This program was intended to further verify FRATE for modeling the structural vibration of a closed boxcar and provide a partial verification of the model for one class of lading--canned goods. The scope of testing also included evaluating the canned good resonances for two types of packaging: corrugated boxes and stretch-wrap plastic.

This test was conducted in two parts. The first part, the truck characterization test, was carried out in the Component Test Laboratory, while the second part took place in the RDL.

Truck characterization was performed to obtain test data on boxcar trucks, as a subsystem separate from the carbody, and to support the mathematical validation model in connection with overall test results. Testing was of static nature, and spring rates and friction forces were measured. Each boxcar truck was positioned in a truck compression fixture for low frequency cyclic (approximately 0.1 Hz) loading. Spring rates and friction forces in the truck were obtained for comparison with a mathematical model. The subsystem test data allows the truck and carbody responses and interaction to be more clearly separated during the post-test model validation activity. Loads were applied separately in vertical and lateral directions and in combination to provide a load simulating carbody roll.



TRUCK CHARACTERIZATION SETUP

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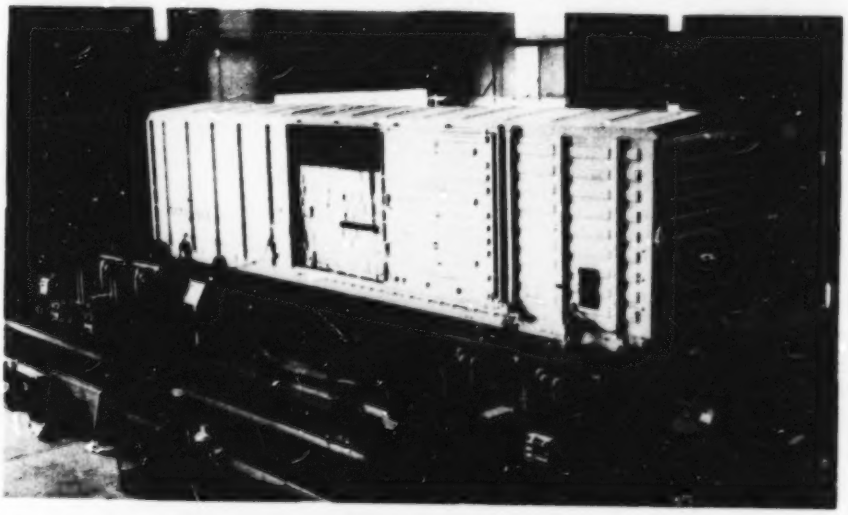
The test exercised the VTU as a variable force/displacement input mechanism. Actuator inputs of torsion, yaw, 1st roll, bounce, pitch, track irregularity (haversine), hunting simulation (lateral), staggered low rail joint profile and random frequency were applied to the test car.

The test sequences were arranged to identify resonant frequencies of the carbody and lading, with and without snubbing devices; then carbody and lading motions during resonant excitation of the vehicle were measured. Also, vehicle responses to various simulated rail service dynamic conditions (i.e., hunting, track irregularity, or staggered low rail joint profile) were recorded. The test vehicle used was Boxcar DOTX 503, a 50 foot hi-cube type boxcar, which is representative of a great number being used in interchange service today.



The following configurations were used:

- Configuration I - Loaded, trucks with active friction snubbers and lading in corrugated containers.
- Configuration II - Loaded without friction snubbers and lading in corrugated containers.
- Configuration III - Empty, without friction snubbers.
- Configuration IV - Loaded, with friction snubbers and lading in stretch-wrapped containers.

The car and lading resonances, along with time histories and Bode and Argand plots from the Configuration II bounce mode best describe the car and lading resonances.

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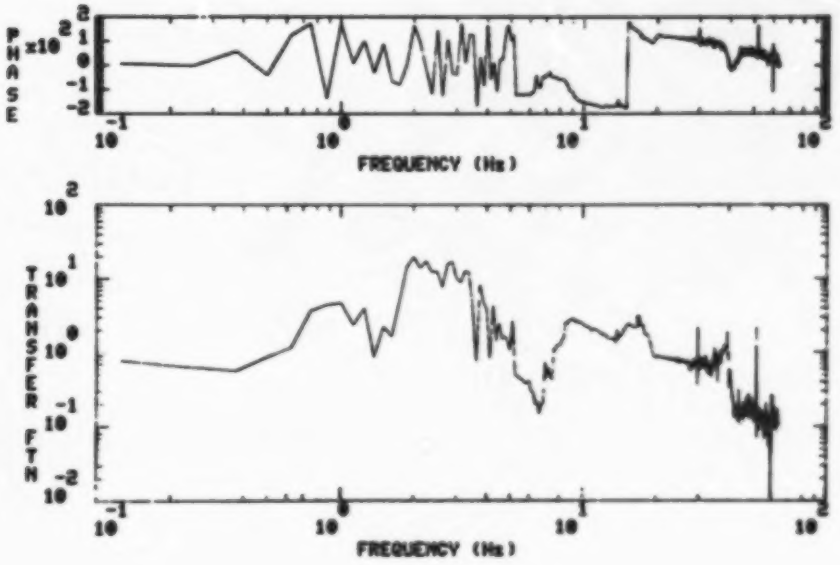
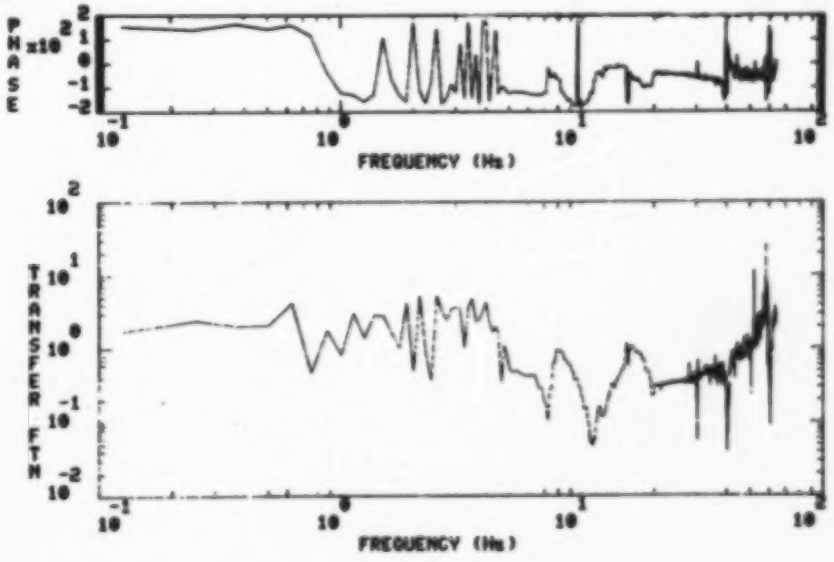
The two different shipping containers had different lading response resonances as shown.

CORRUGATED BOX PACKAGING



STRETCH-WRAP PACKAGING



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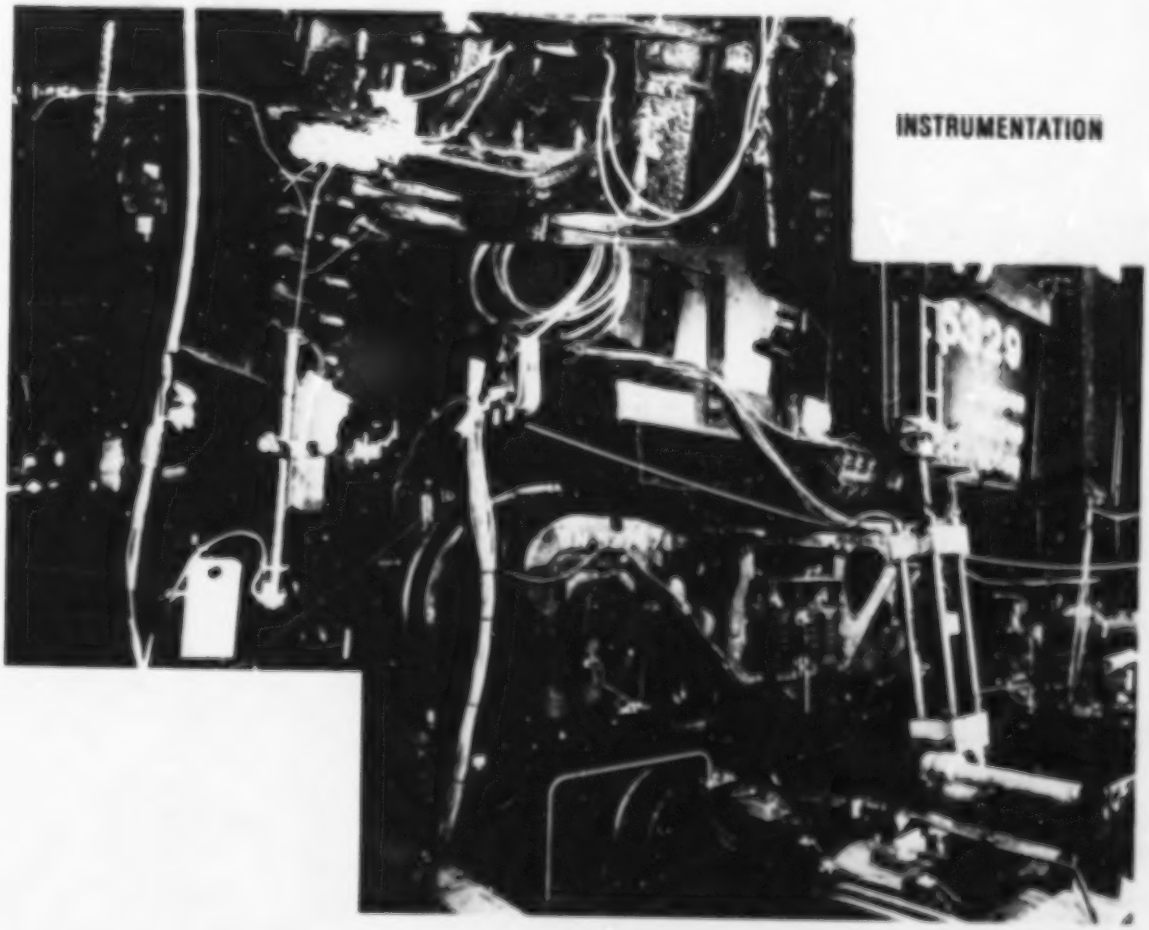
Concluding Remarks

The objectives of improved ground transportation included better service, higher efficiency, increased safety, higher speeds, greater comfort and reduced lading damage. The results of these test programs provide a first step in the use of a powerful engineering tool to achieve these objectives. Further laboratory application will include the performance of much needed tests of locomotives, freight and passenger cars, transit vehicles and advanced track systems under environmentally controlled conditions. Economical, in-depth testing of the equipment coupled with appropriate analysis will lead to lower costs and increased safety.

The content of this document was compiled through the efforts of many TTC personnel. Dan Inskeep, Boeing Services International, and Wade Dorland, Federal Railroad Administration, were the key engineers in this endeavor.



INSTRUMENTATION

GPO 834-071

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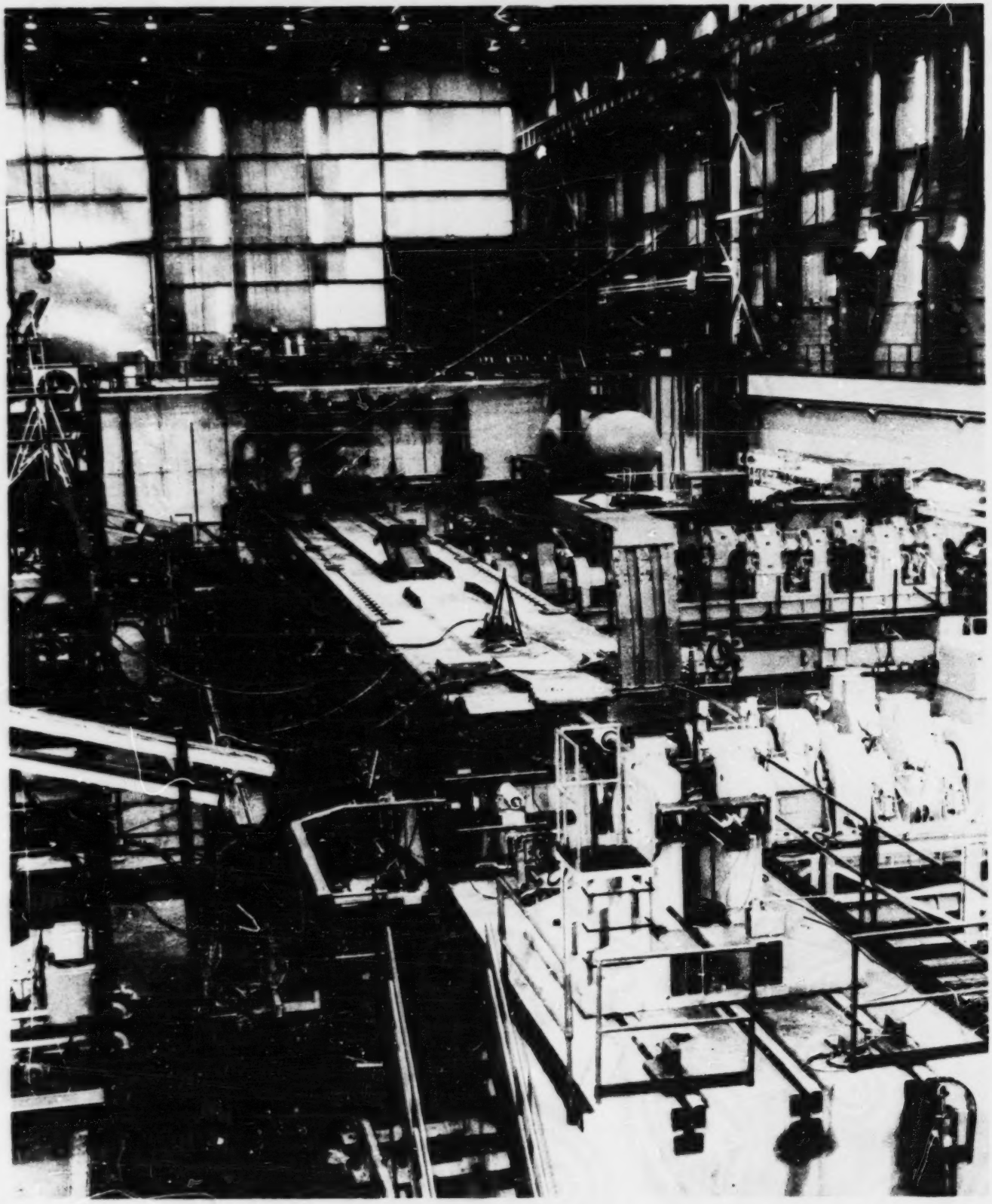
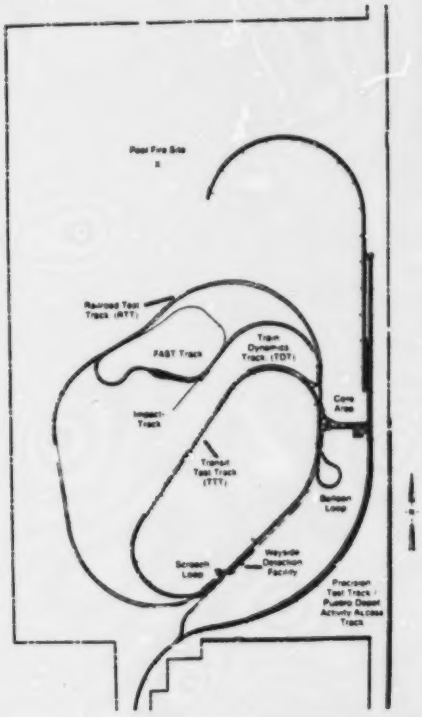


FLATCAR DEMONSTRATION TEST ON RDU - LOOKING WEST FROM MEZZANINE

The Rail Dynamics Laboratory is located within the core area of the Transportation Test Center, 25 miles northeast of Pueblo, Colorado.



Transportation Test Center

Pueblo, Colorado

U.S. Department of Transportation
Federal Railroad Administration

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JANUARY, 1982